

5. SUMMARY OF FORECAST VERIFICATION

5.1 ANNUAL FORECAST VERIFICATION

Verification of warning positions and intensities at initial, 24-, 48- and 72-hour forecast periods was made against the final best track. The (scalar) track forecast, along-track and cross-track errors (illustrated in Figure 5-1) were calculated for each verifying JTWC forecast. These data, in addition to a detailed summary for each tropical cyclone, are included as Chapter 6. This section summarizes verification data for 1995 and contrasts it with annual verification statistics from previous years.

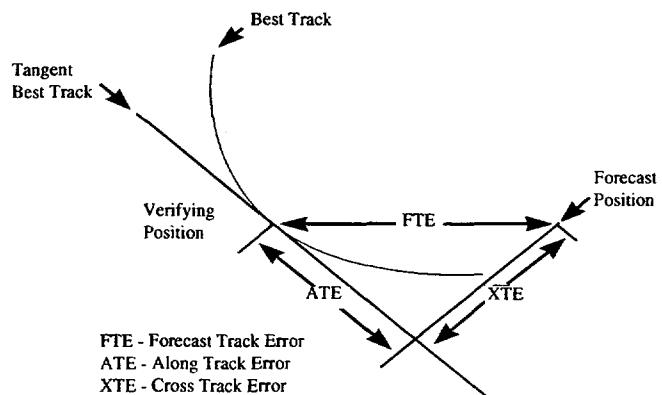
5.1.1 NORTHWEST PACIFIC OCEAN — The frequency distributions of errors for initial warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-2a through 5-2f. Table 5-1 includes mean track, along-track and cross-track errors for 1978-1994. Figure 5-3 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours for the past 20 years. Table 5-2 lists annual mean track errors from 1959, when

the JTWC was founded, until the present.

5.1.2 NORTH INDIAN OCEAN — The frequency distributions of errors for warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-4a through 5-4f, respectively. Table 5-3 includes mean track, along-track and cross-track errors for 1978-1995. Figure 5-5 shows mean track errors and a 5-year running mean of track errors at 24-, 48- and 72-hours for the past 20 years.

5.1.3 SOUTH PACIFIC AND SOUTH INDIAN OCEANS — The frequency distributions of errors for warning positions and 12-, 24-, 36-, 48- and 72-hour forecasts are presented in Figures 5-6a through 5-6f, respectively. Table 5-4 includes mean track, along-track and cross-track errors for 1981-1995. Figure 5-7 shows mean track errors and a 5-year running mean of track errors at 24-, 48-, and 72-hours for the 15 years that the JTWC has issued warnings in the region.

Figure 5-1 Definition of cross-track error (XTE), along-track error (ATE) and forecast track error (FTE). In this example, the XTE is positive (to the right of the best track) and the ATE is negative (behind or slower than the best track).



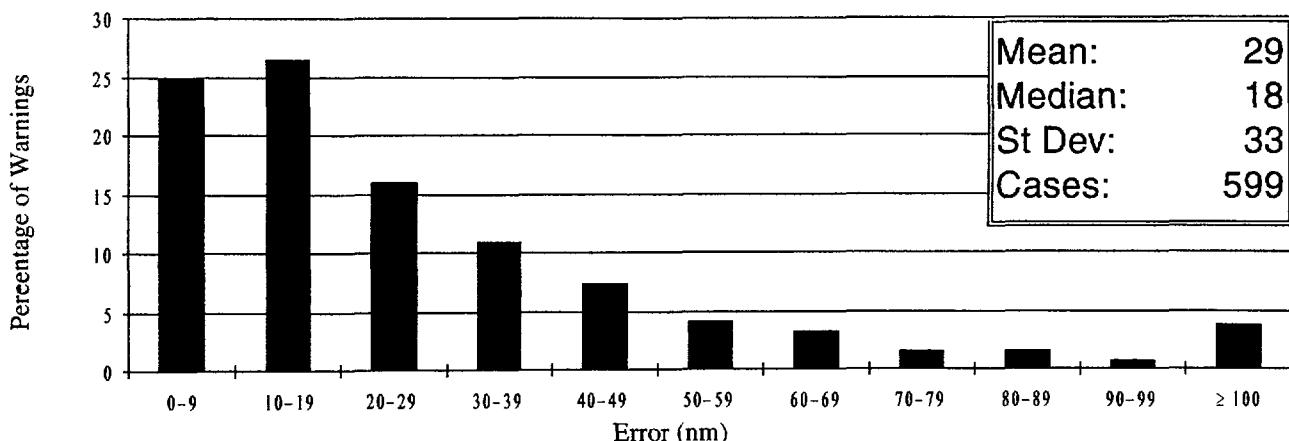


Figure 5-2a Frequency distribution of initial warning position errors (10-nm increments) for western North Pacific Ocean tropical cyclones in 1995. The largest error, 279 nm, occurred on Tropical Depression 32W.

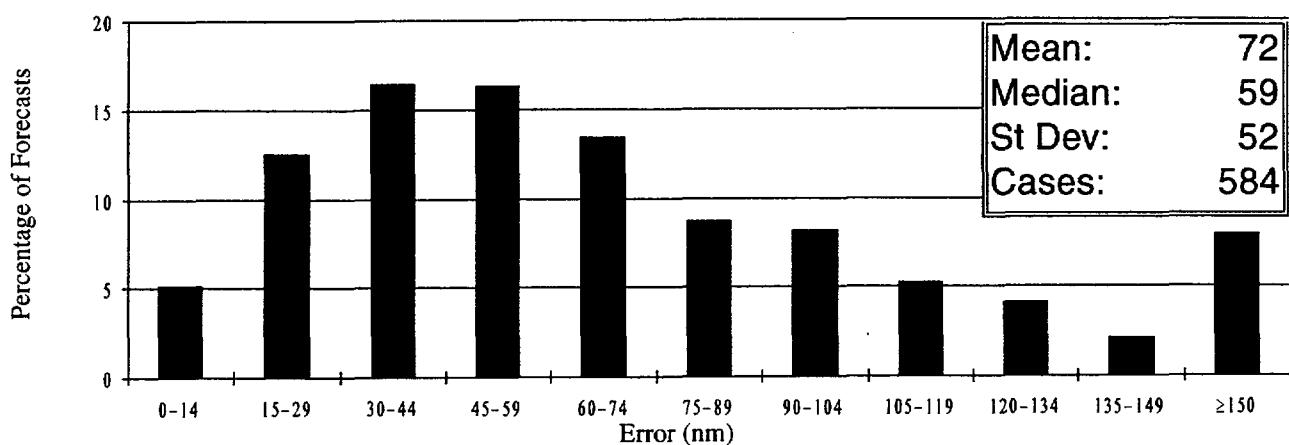


Figure 5-2b Frequency distribution of 12-hour track forecast errors (15-nm increments) for western North Pacific Ocean tropical cyclones in 1995. The largest error, 460 nm, occurred on Tropical Depression 32W.

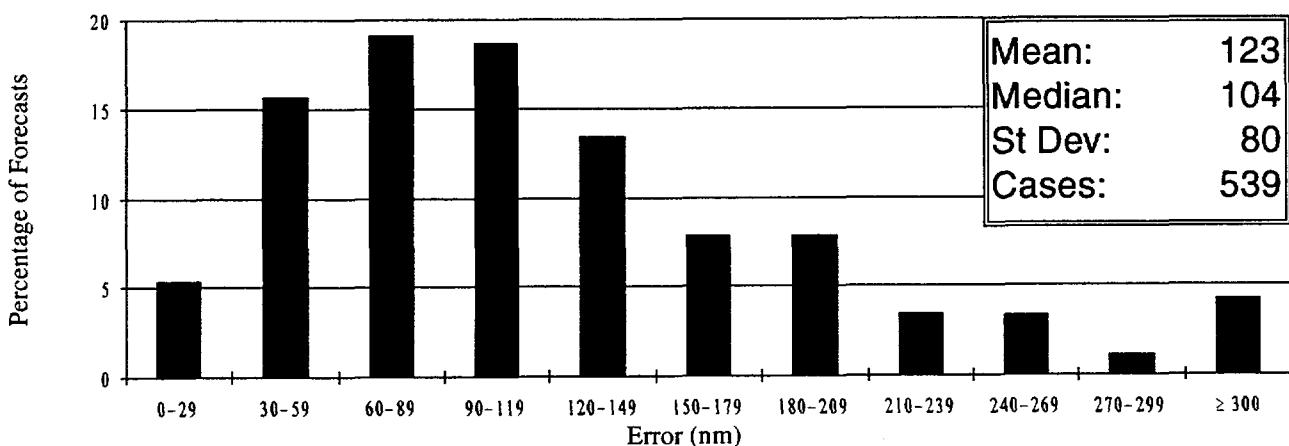


Figure 5-2c Frequency distribution of 24-hour track forecast errors (30-nm increments) for western North Pacific Ocean tropical cyclones in 1995. The largest error, 618 nm, occurred on Tropical Storm Deanna (03W).

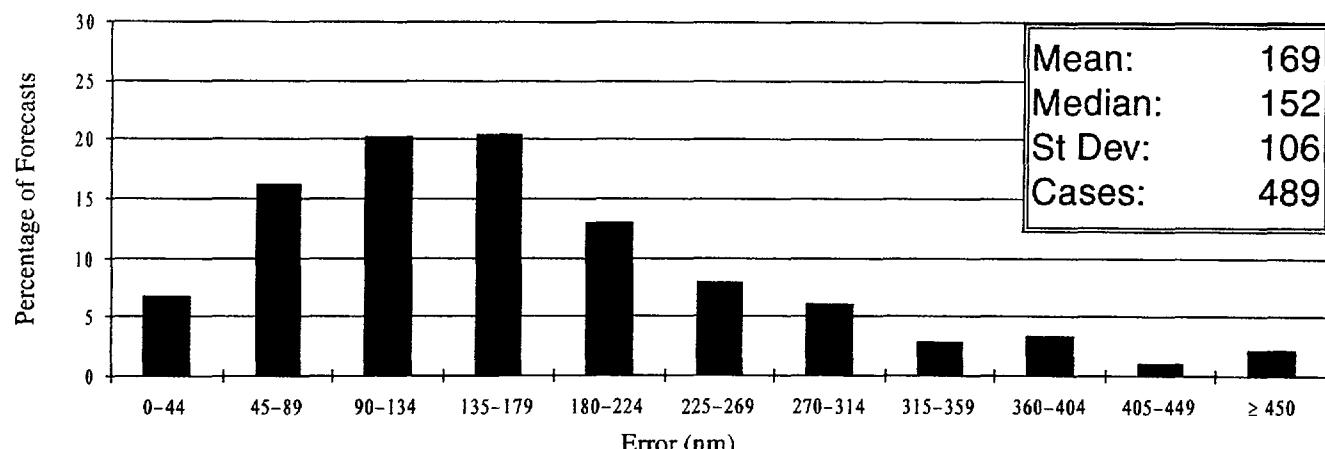


Figure 5-2d Frequency distribution of 36-hour track forecast errors (45-nm increments) for western North Pacific Ocean tropical cyclones in 1995. The largest error, 743 nm, occurred on Super Typhoon Ward (26W).

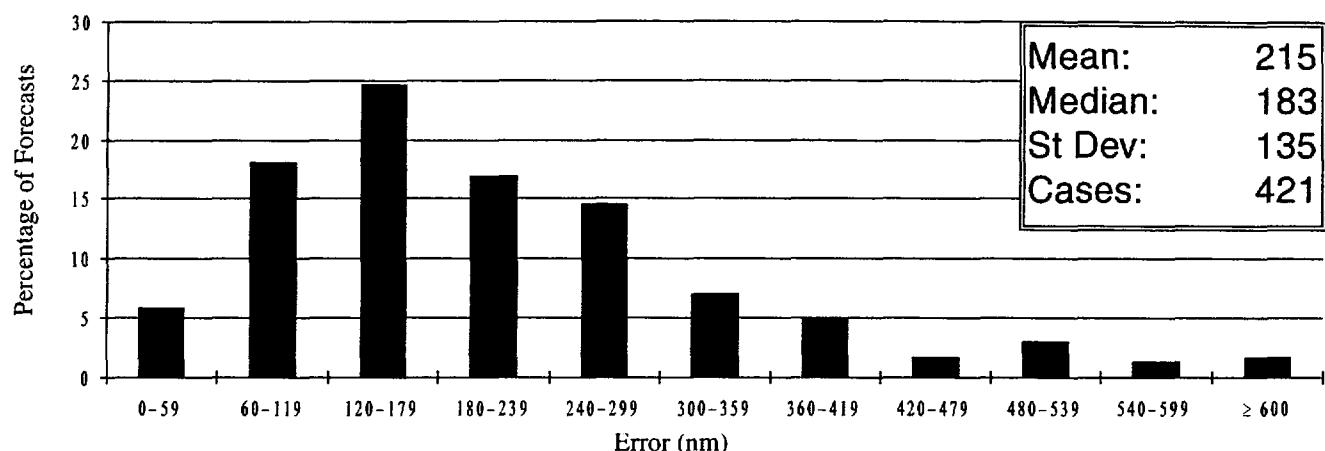


Figure 5-2e Frequency distribution of 48-hour track forecast errors (60-nm increments) for western North Pacific Ocean tropical cyclones in 1995. The largest error, 760 nm, occurred on Tropical Storm Val (25W).

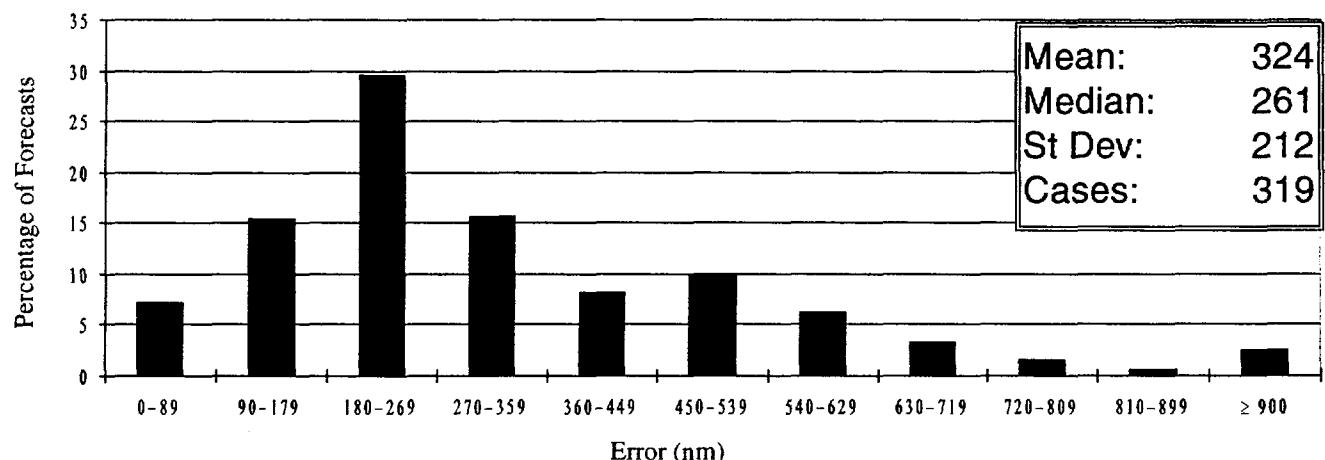


Figure 5-2f Frequency distribution of 72-hour track forecast errors (90-nm increments) for western North Pacific Ocean tropical cyclones in 1995. The largest error, 1386 nm, occurred on Tropical Storm Val (25W).

		INITIAL WARNING POSITION AND FORECAST ERRORS (NM) FOR THE WESTERN NORTH PACIFIC FOR 1981-1995.														
YEAR	NUMBER OF WARNINGS	NUMBER OF	INITIAL	NUMBER OF		24-HOUR		NUMBER OF		48-HOUR		NUMBER OF		72-HOUR		
		POSITION	FORECASTS	TRACK		ALONG	CROSS	FORECASTS		TRACK	ALONG	CROSS	FORECASTS	TRACK	ALONG	CROSS
1981	584	25	466	124		80	77	348		221	146	131	246	334	206	219
1982	786	19	666	113		74	70	532		238	162	142	425	342	223	211
1983	445	16	342	117		76	73	253		260	169	164	194	407	259	263
1984	611	22	492	117		84	64	378		232	163	131	286	363	238	216
1985	592	18	477	117		80	68	336		231	153	138	241	367	230	227
1986	743	21	645	126		85	70	535		261	183	151	412	394	276	227
1987	657	18	563	107		71	64	465		204	134	127	389	303	198	186
1988	465	23	373	114		85	58	262		216	170	103	183	315	244	159
1989	710	20	625	120		83	69	481		231	162	127	363	350	265	177
1990	794	21	658	103		72	60	525		203	148	110	432	310	225	168
1991	835	22	733	96		69	53	599		185	137	97	484	287	229	146
1992	941	25	841	107		77	59	687		205	143	116	568	305	210	172
1993	853	26	725	112		79	63	570		212	151	117	437	321	226	173
1994	1058	24	932	98		85	62	753		176	158	105	608	242	218	144
1995	599	29	539	123		89	67	421		215	159	117	319	325	240	167
15-YEAR AVERAGE																
1981-1995		709	22	605	113	79	65	466	219	162	125	372	331	232	190	

Note: Cross-track and along-track errors were adopted by the JTWC in 1986. Right-angle errors (used prior to 1986) were recomputed as cross-track and along-track errors after-the-fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track errors.

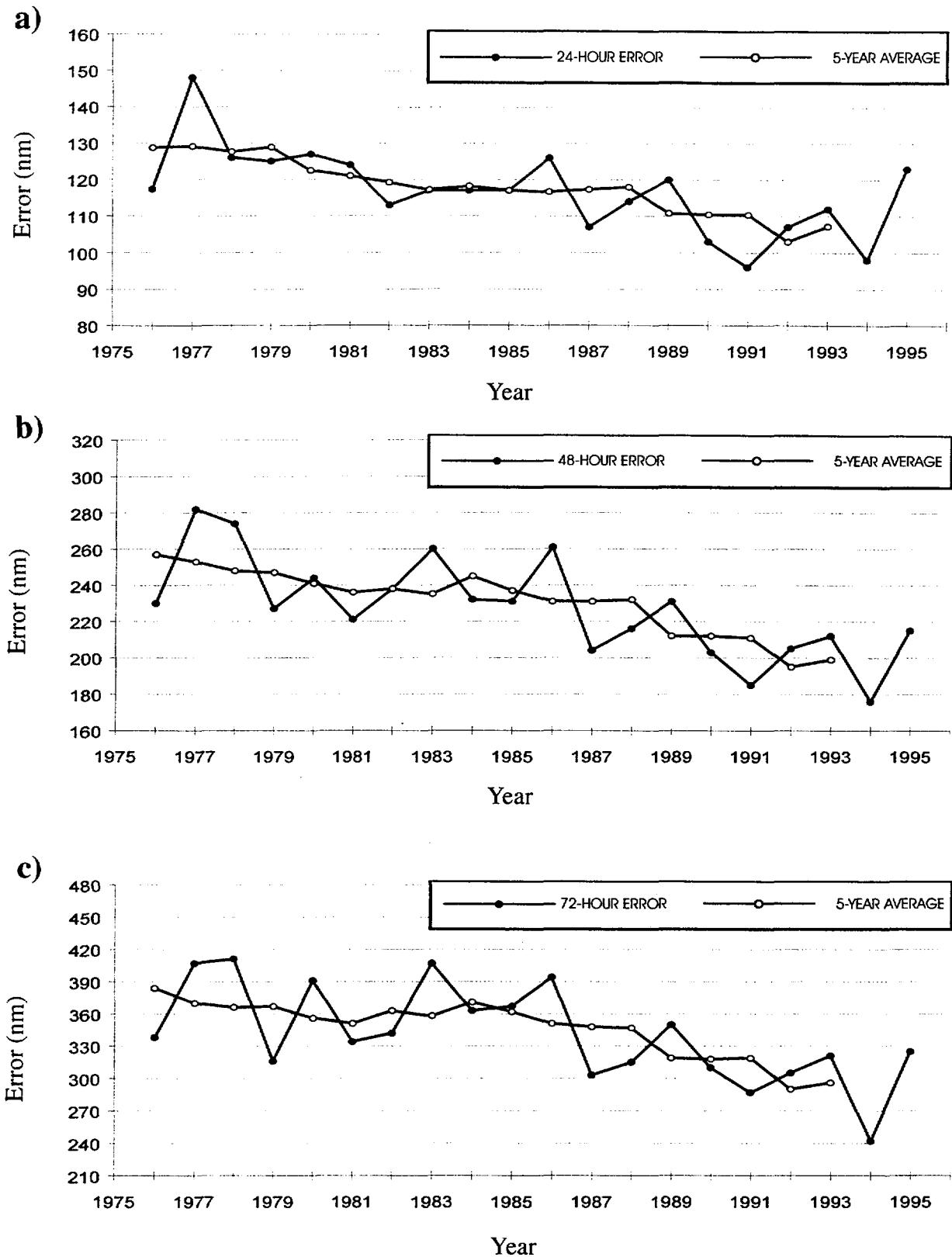


Figure 5-3 Mean track forecast error (nm) and 5-year running mean for a) 24 hours, b) 48 hours and c) 72 hours for western North Pacific Ocean tropical cyclones for the period 1976 to 1995.

Table 5-2

MEAN FORECAST TRACK ERRORS (NM) FOR WESTERN
NORTH PACIFIC TROPICAL CYCLONES FOR 1959-1995

YEAR	24-HOUR				48-HOUR				72-HOUR			
	TY ¹	CROSS		ALONG	TY ¹	CROSS		ALONG	TY ¹	CROSS		ALONG
		TC	TRACK ²	TRACK ²		TC	TRACK ²	TRACK ²		TC	TRACK ²	TRACK ²
1959	117*				267*							
1960	177*				354*							
1961	136				274							
1962	144				287				476			
1963	127				246				374			
1964	133				284				429			
1965	151				303				418			
1966	136				280				432			
1967	125				276				414			
1968	105				229				337			
1969	111				237				349			
1970	98	104			181	190			272	279		
1971	99	111	64		203	212	118		308	317	177	
1972	116	117	72		245	245	146		382	381	210	
1973	102	108	74		193	197	134		245	253	162	
1974	114	120	78		218	226	157		357	348	245	
1975	129	138	84		279	288	181		442	450	290	
1976	117	117	71		232	230	132		336	338	202	
1977	140	148	83		266	283	157		390	407	228	
1978	120	127	71	87	241	271	151	194	459	410	218	296
1979	113	124	76	81	219	226	138	146	319	316	182	214
1980	116	126	76	86	221	243	147	165	362	389	230	266
1981	117	123	77	80	215	220	131	146	342	334	219	206
1982	114	113	70	74	229	237	142	162	337	341	211	223
1983	110	117	73	76	247	259	164	169	384	405	263	259
1984	110	117	64	84	228	233	131	163	361	363	216	238
1985	112	117	68	80	228	231	138	153	355	367	227	230
1986	117	121	70	85	261	261	151	183	403	394	227	276
1987	101	107	64	71	211	204	127	134	318	303	186	198
1988	107	114	58	85	222	216	103	170	327	315	159	244
1989	107	120	69	83	214	231	127	162	325	350	177	265
1990	98	103	70	81	191	203	138	162	299	310	211	242
1991	93	96	53	69	187	185	97	137	298	286	146	229
1992	97	107	59	77	194	205	116	143	295	305	172	210
1993	102	112	63	79	205	212	117	151	320	321	173	226
1994	96	98	53	71	172	176	101	123	244	242	146	163
1995	105	123	89	67	200	215	159	117	311	325	240	167

1. Forecasts were verified for typhoons when intensities were at least 35kt (18m/sec).

2. Cross-track and along-track errors were adopted by the JTWC in 1986. Right angle errors (used prior to 1986) were recomputed as cross-track errors after-the-fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track.

* Forecast positions north of 35° north latitude were not verified.

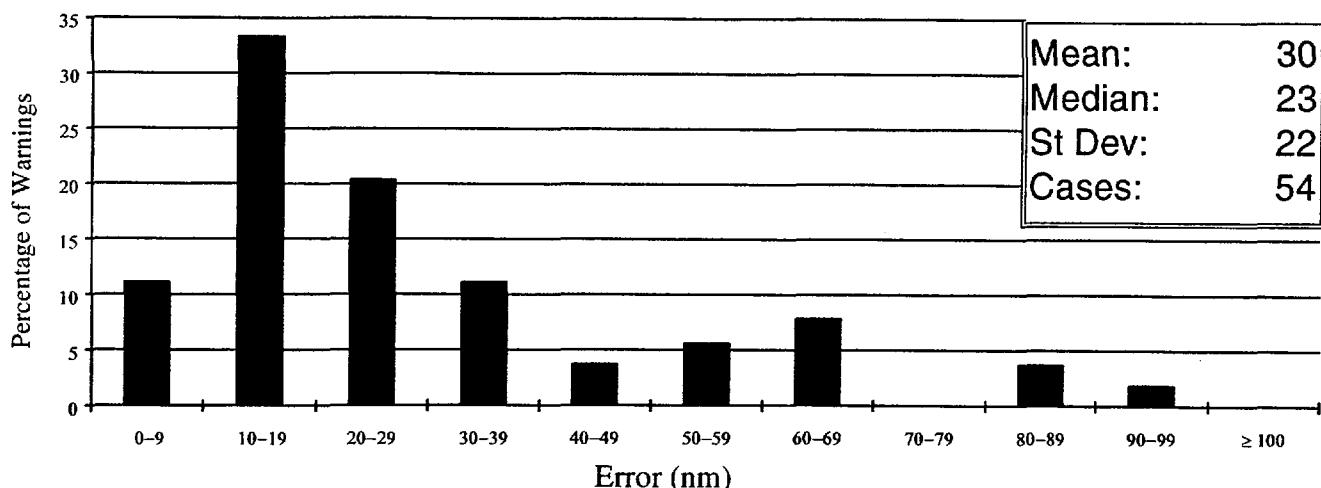


Figure 5-4a Frequency distribution of initial warning position errors (10-nm increments) for North Indian Ocean tropical cyclones in 1995. The largest error, 91nm, was on TC02A.

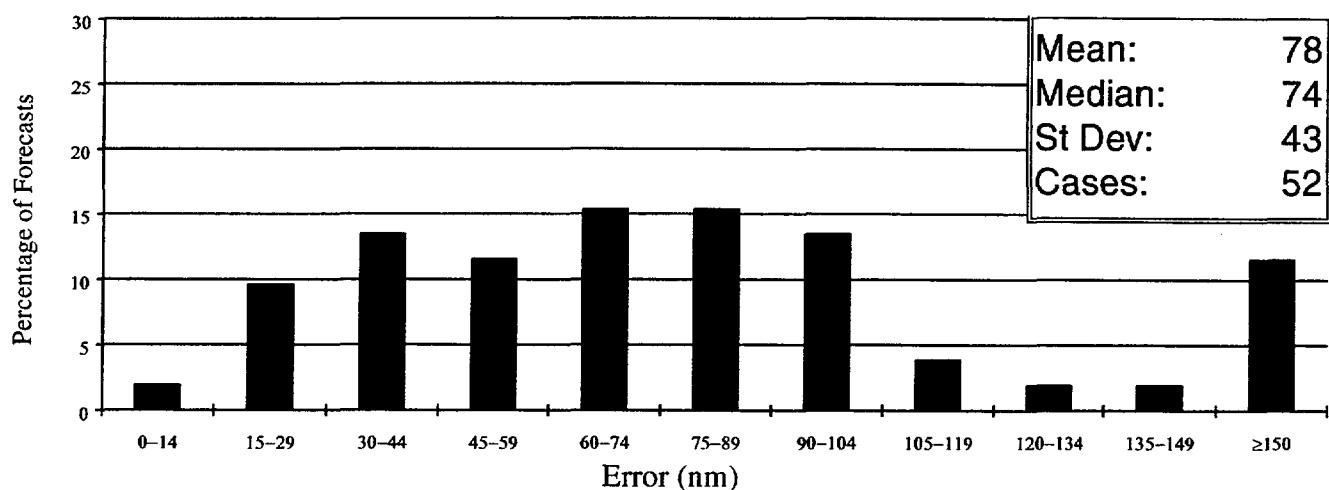


Figure 5-4b Frequency distribution of 12-hour track forecast errors (15-nm increments) for North Indian Ocean tropical cyclones in 1995. The largest error, 181nm, was on TC04B.

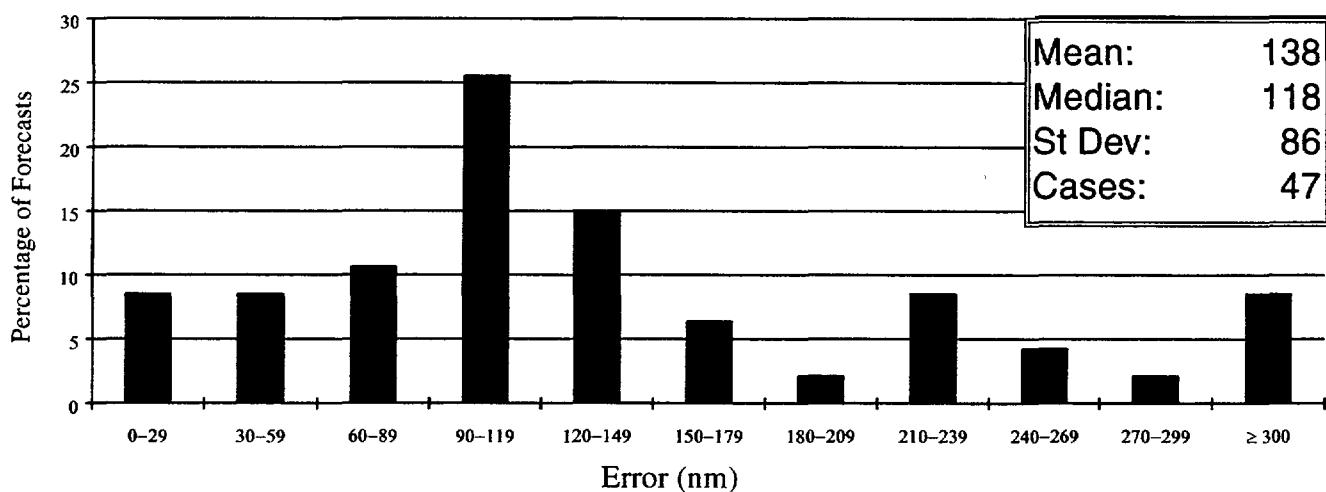


Figure 5-4c Frequency distribution of 24-hour track forecast errors (30-nm increments) for North Indian Ocean tropical cyclones in 1995. The largest error, 326 nm, was on TC02A.

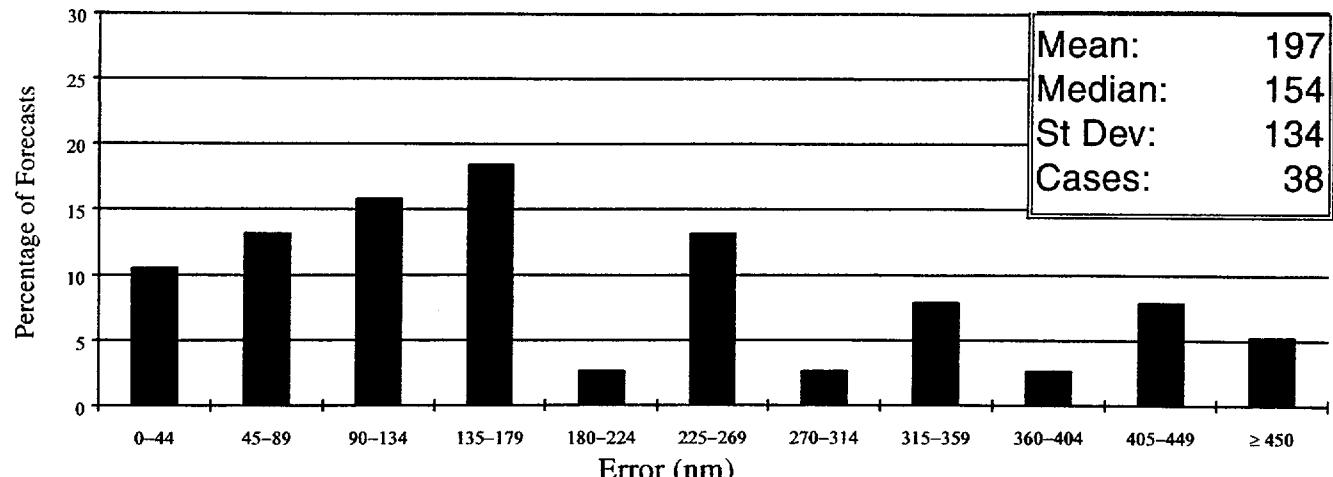


Figure 5-4d Frequency distribution of 36-hour track forecast errors (45-nm increments) for North Indian Ocean tropical cyclones in 1995. The largest error, 502 nm, was on TC04B.

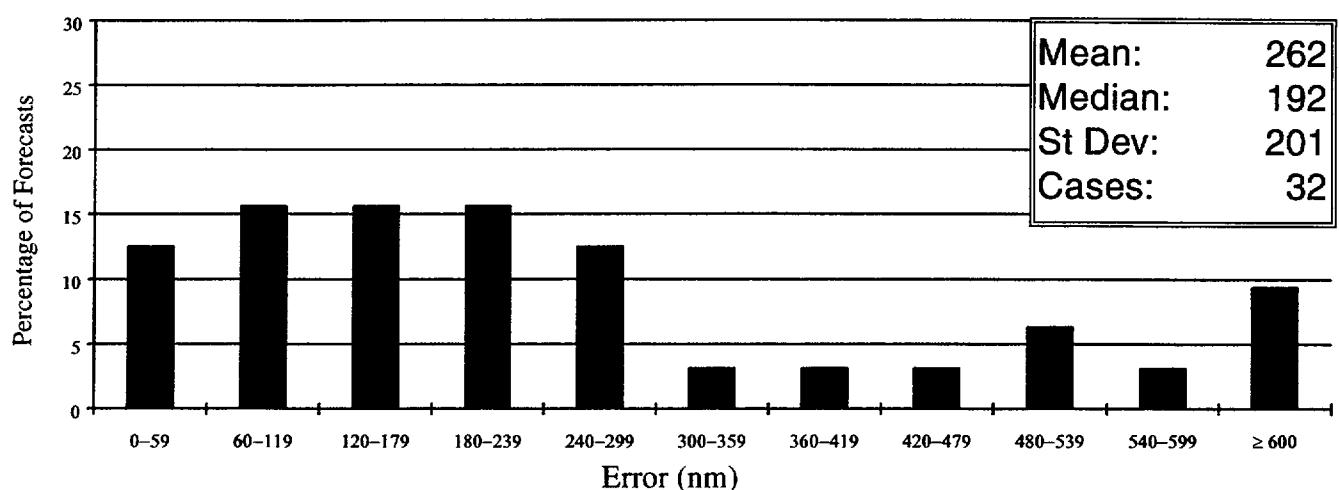


Figure 5-4e Frequency distribution of 48-hour track forecast errors (60-nm increments) for North Indian Ocean tropical cyclones in 1995. The largest error, 728 nm, was on TC04B.

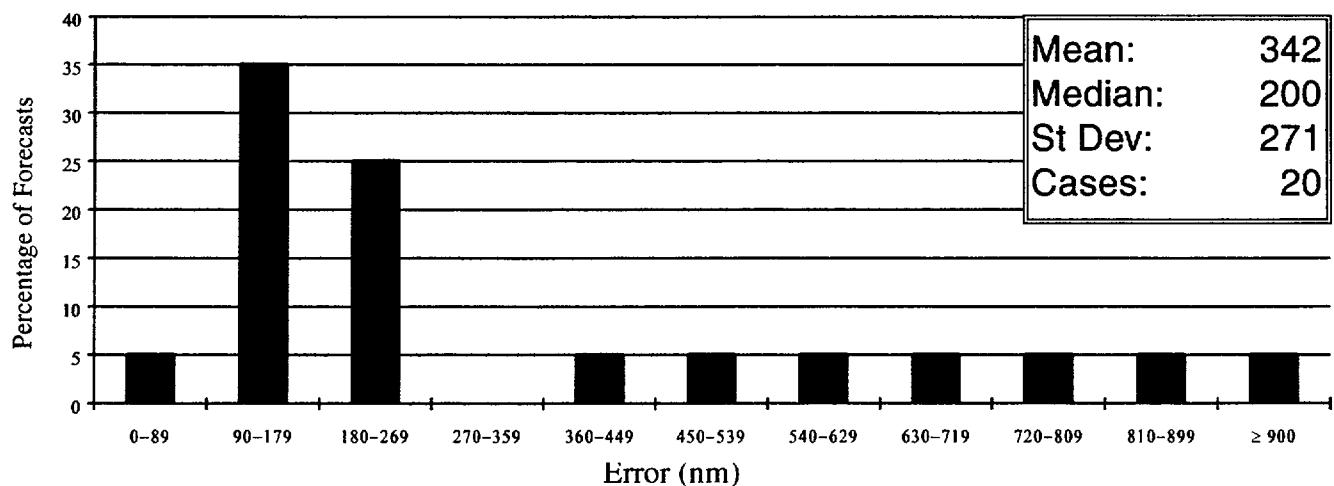


Figure 5-4f Frequency distribution of 72-hour track forecast errors (90-nm increments) for North Indian Ocean tropical cyclones in 1995. The largest error, 924 nm, was on TC04B.

		INITIAL POSITION AND FORECAST POSITION ERRORS (NM) FOR THE NORTH INDIAN OCEAN FOR 1981-1995															
YEAR	NUMBER OF WARNINGS	NUMBER OF	INITIAL	NUMBER OF		24-HOUR			NUMBER OF		48-HOUR			NUMBER OF		72-HOUR	
		POSITION	FORECASTS	TRACK		ALONG	CROSS		FORECASTS		ALONG	CROSS		FORECASTS	TRACK	ALONG	CROSS
1981	41	28	29	109	76	63	2	176	120	109	5	197	150	111			
1982	55	35	37	138	110	68	17	368	292	209	7	762	653	332			
1983	18	38	7	117	90	50	18	153	137	53	0						
1984	67	33	42	154	124	67	20	274	217	139	16	388	339	121			
1985	53	31	30	122	102	53	8	242	119	194	0						
1986	28	52	16	134	118	53	7	168	131	80	5	269	189	180			
1987	83	42	54	144	97	100	25	205	125	140	21	305	219	188			
1988	44	34	30	120	89	63	18	219	112	176	12	409	227	303			
1989	44	19	33	88	62	50	17	146	94	86	12	216	164	111			
1990	46	31	36	101	85	43	24	146	117	67	17	185	130	104			
1991	56	38	43	129	107	54	27	235	200	89	14	450	356	178			
1992	191	35	149	128	73	86	100	244	141	166	62	398	276	218			
1993	36	27	28	125	87	79	20	198	171	74	12	231	176	116			
1994	60	25	44	97	80	44	28	153	124	63	13	213	177	92			
1995	54	30	47	138	119	58	32	262	247	77	20	342	304	109			
15 YEAR AVERAGE																	
1981-1995	58	33	42	123	94	62	24	213	156	115	14	336	258	166			

Cross-track and along-track errors were adopted by the JTWC in 1986. Right angle errors (used prior to 1986) were recomputed as cross-track and along-track errors after-the-fact to extend the data base. See Figure 5-1 for the definitions of cross-track and along-track errors.

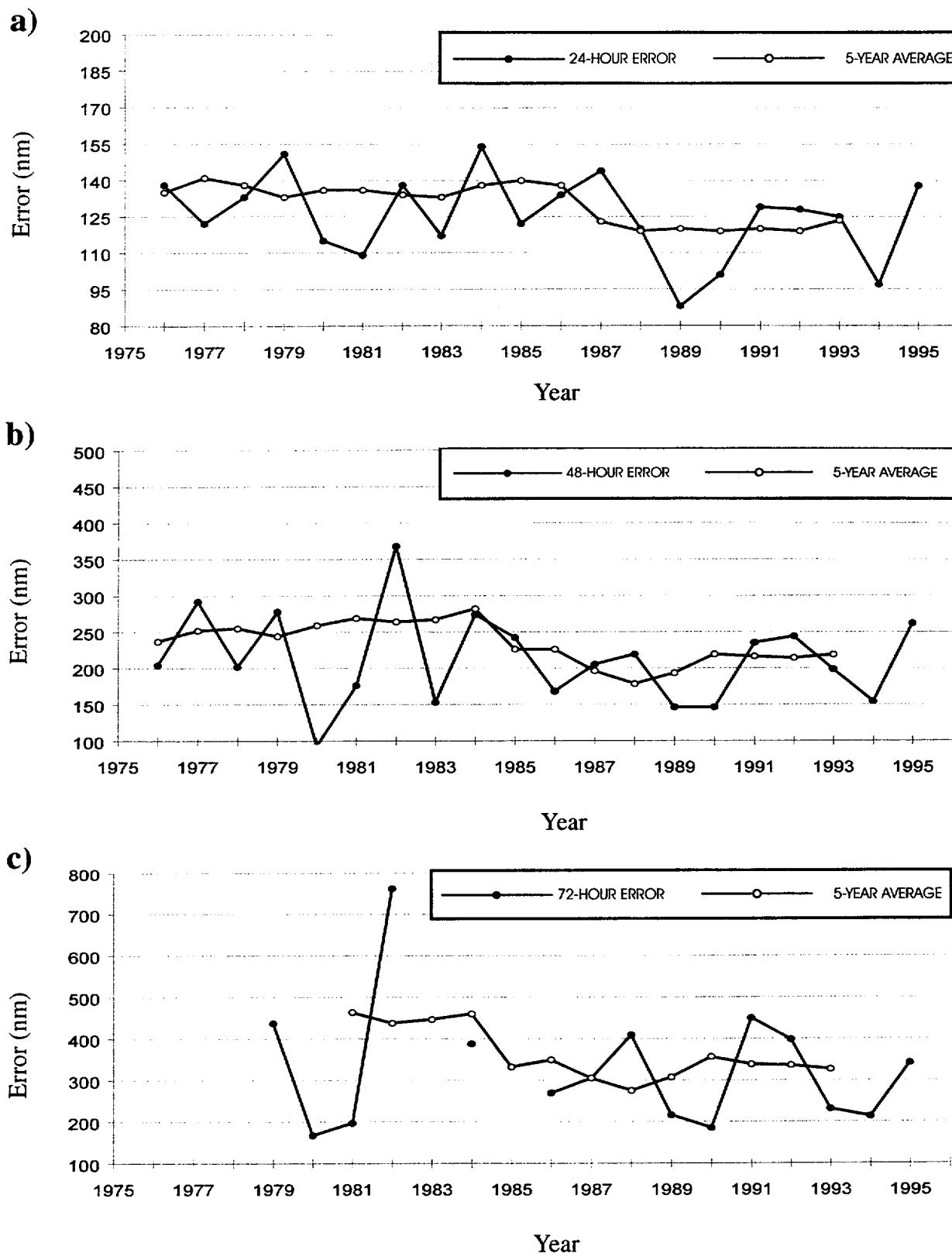


Figure 5-5 Mean track forecast error (nm) and 5-year running mean for a) 24 hours, b) 48 hours and c) 72 hours for North Indian Ocean tropical cyclones for the period 1976 to 1995.

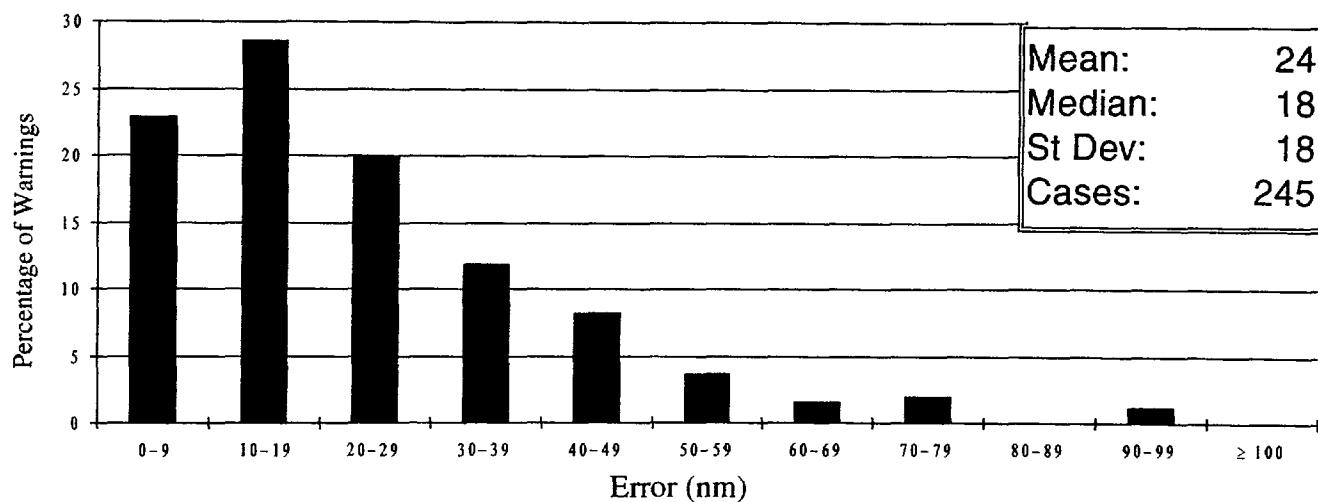


Figure 5-6a Frequency distribution of initial warning position errors (10-nm increments) for South Pacific and South Indian Ocean tropical cyclones in 1995. The largest error, 243 nm, occurred on Tropical Cyclone 05P (William).

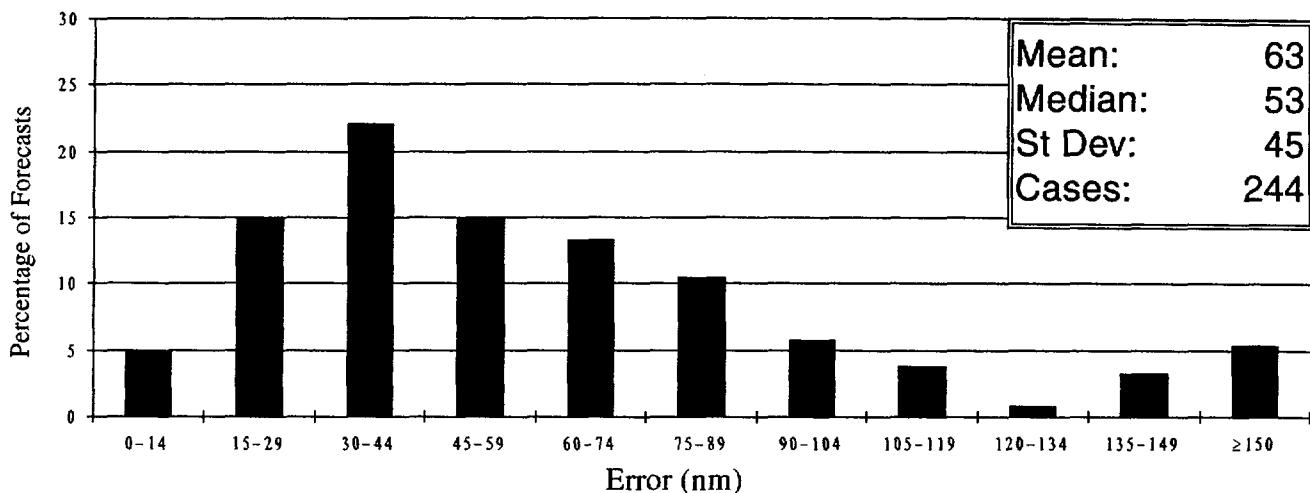


Figure 5-6b Frequency distribution of 12-hour track forecast errors (15-nm increments) for South Pacific and South Indian Ocean tropical cyclones in 1995. The largest error, 341 nm, occurred on Tropical Cyclone 05P (William).

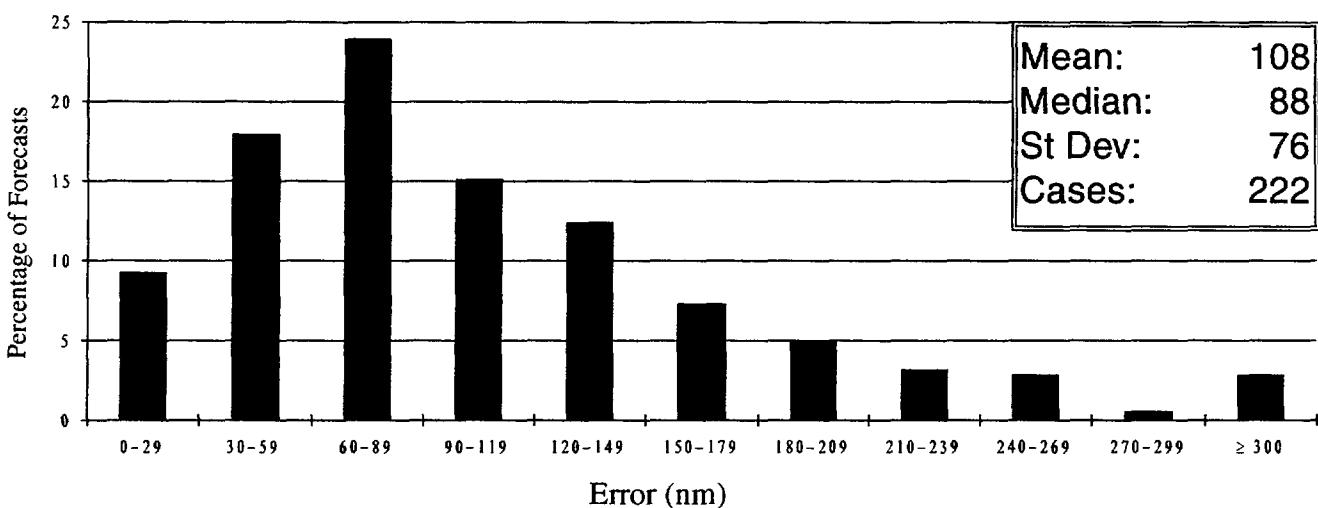


Figure 5-6c Frequency distribution of 24-hour track forecast errors (30-nm increments) for South Pacific and South Indian Ocean tropical cyclones in 1995. The largest error, 492 nm, occurred on Tropical Cyclone 14P (Violet).

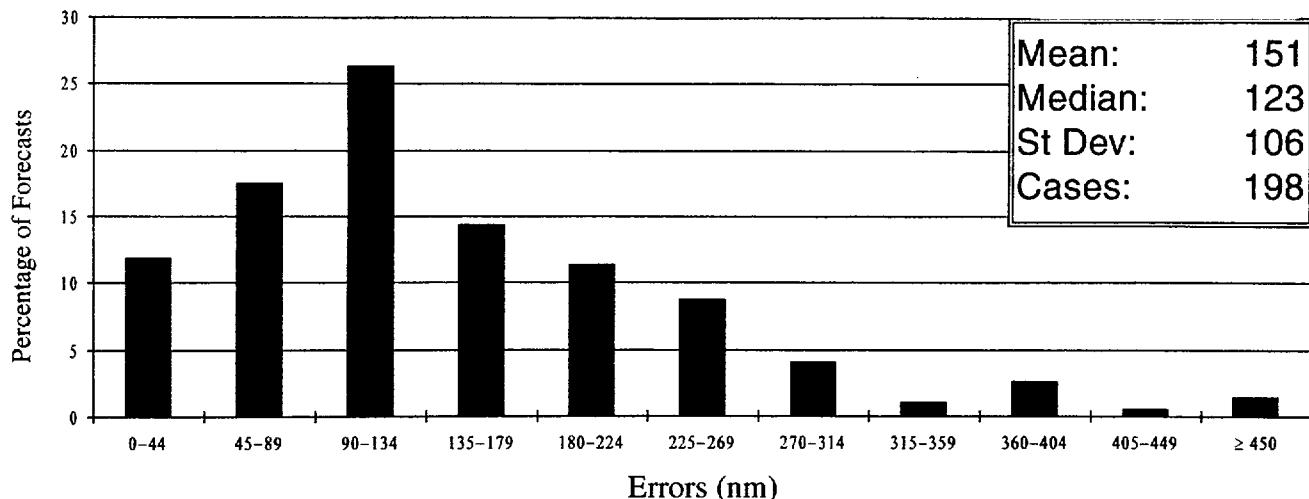


Figure 5-6d Frequency distribution of 36-hour track forecast errors (45-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1995. The largest error, 757 nm, occurred on Tropical Cyclone 14P (Violet).

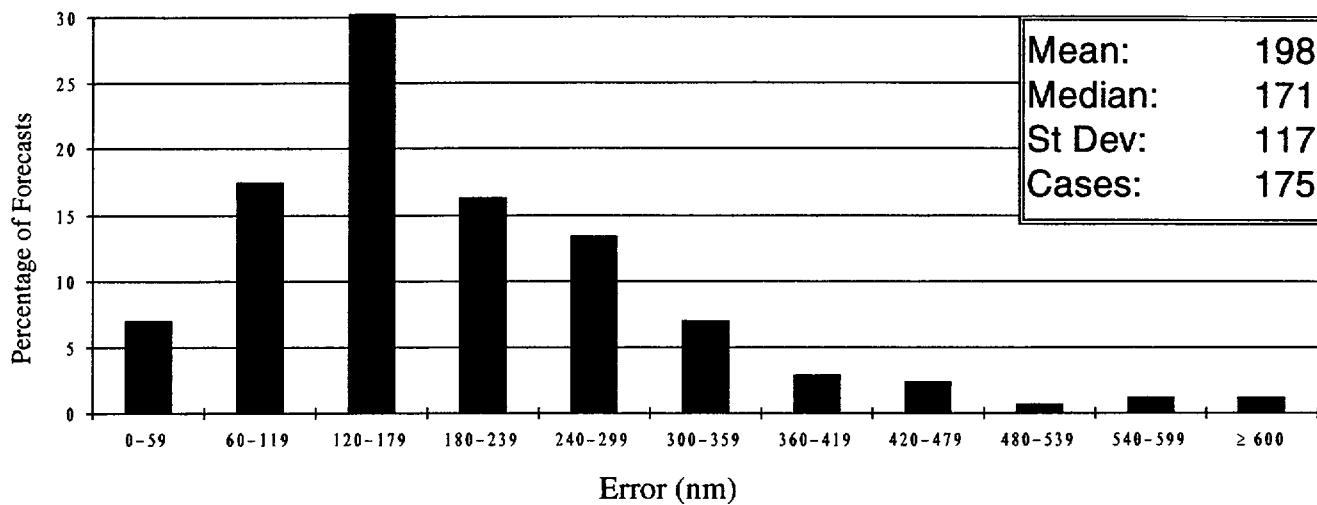


Figure 5-6e Frequency distribution of 48-hour track forecast errors (60-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1995. The largest error, 622 nm, occurred on Tropical Cyclone 19S (Marlene).

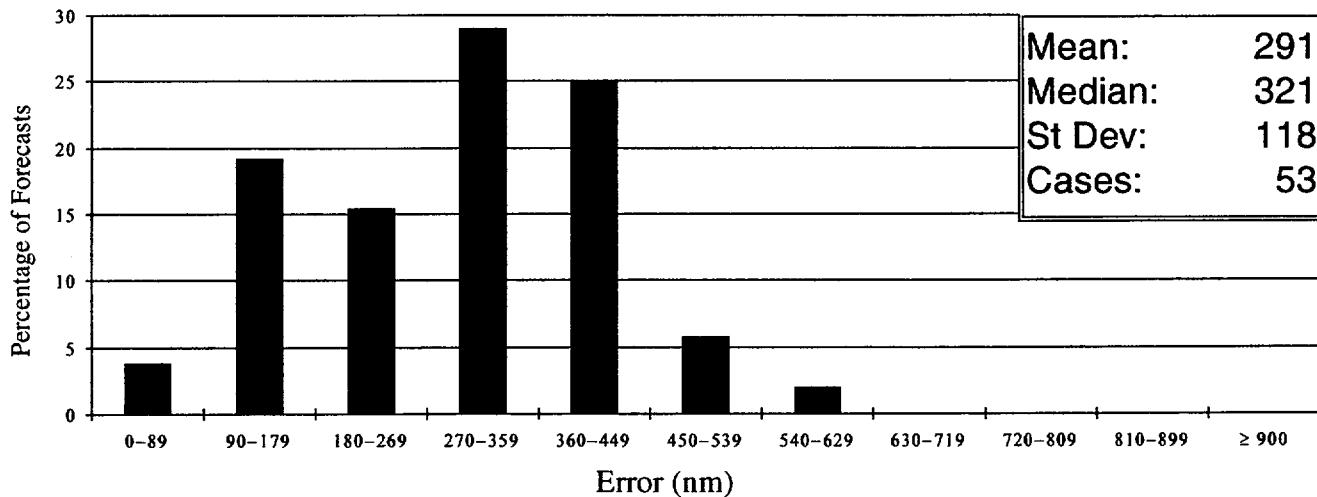


Figure 5-6f Frequency distribution of 72-hour track forecast errors (120-nm increments) for in the South Pacific and South Indian Ocean tropical cyclones in 1995. The largest error, 565 nm, occurred on Tropical Cyclone 22P (Agnes).

		INITIAL POSITION AND FORECAST POSITION ERRORS (NM) FOR THE SOUTHERN HEMISPHERE FOR 1981-1995											
YEAR	NUMBER OF WARNINGS	INITIAL	NUMBER OF	TRACK	24-HOUR		NUMBER OF FORECASTS	48-HOUR		NUMBER OF FORECASTS	72-HOUR		
		POSITION	FORECASTS		ALONG	CROSS		TRACK	ALONG		TRACK	ALONG	CROSS
1981	226	48	190	165	103	106	140	315	204	201			
1982	275	38	238	144	98	86	176	274	188	164			
1983*	191	35	163	130	88	77	126	241	158	145			
1984	301	36	252	133	90	79	191	231	159	134			
1985*	306	36	257	134	92	79	193	236	169	132			
1986*	279	40	227	129	86	77	171	262	169	164			
1987*	189	46	138	145	94	90	101	280	153	138			
1988*	204	34	99	146	98	83	48	290	246	144			
1989*	287	31	242	124	84	73	186	240	166	136			
1990*	272	27	228	143	105	74	177	263	178	152			
1991*	264	24	231	115	75	69	185	220	152	129			
1992*	267	28	230	124	91	64	208	240	177	129			
1993*	257	21	225	102	74	57	176	199	142	114			
1994*	386	28	345	115	77	68	282	224	147	134			
1995**	245	24	222	108	82	55	175	198	144	108	53	291	169
AVERAGE													190
1981-1995	263	33	219	130	89	76	169	248	170	142	53	291	169
													190

* These statistics are for JTWC forecasts only. NPMOC statistics are not included.
** JTWC began publishing 72-hour forecast verification in 1995.
Cross-track and along-track errors were adopted by the JTWC in 1986. Right-angle (used prior to 1986) were recomputed as cross-track and along-track errors after-the-fact to extend the data base.
See Figure 5-1 for the definitions of cross-track and along-track errors.

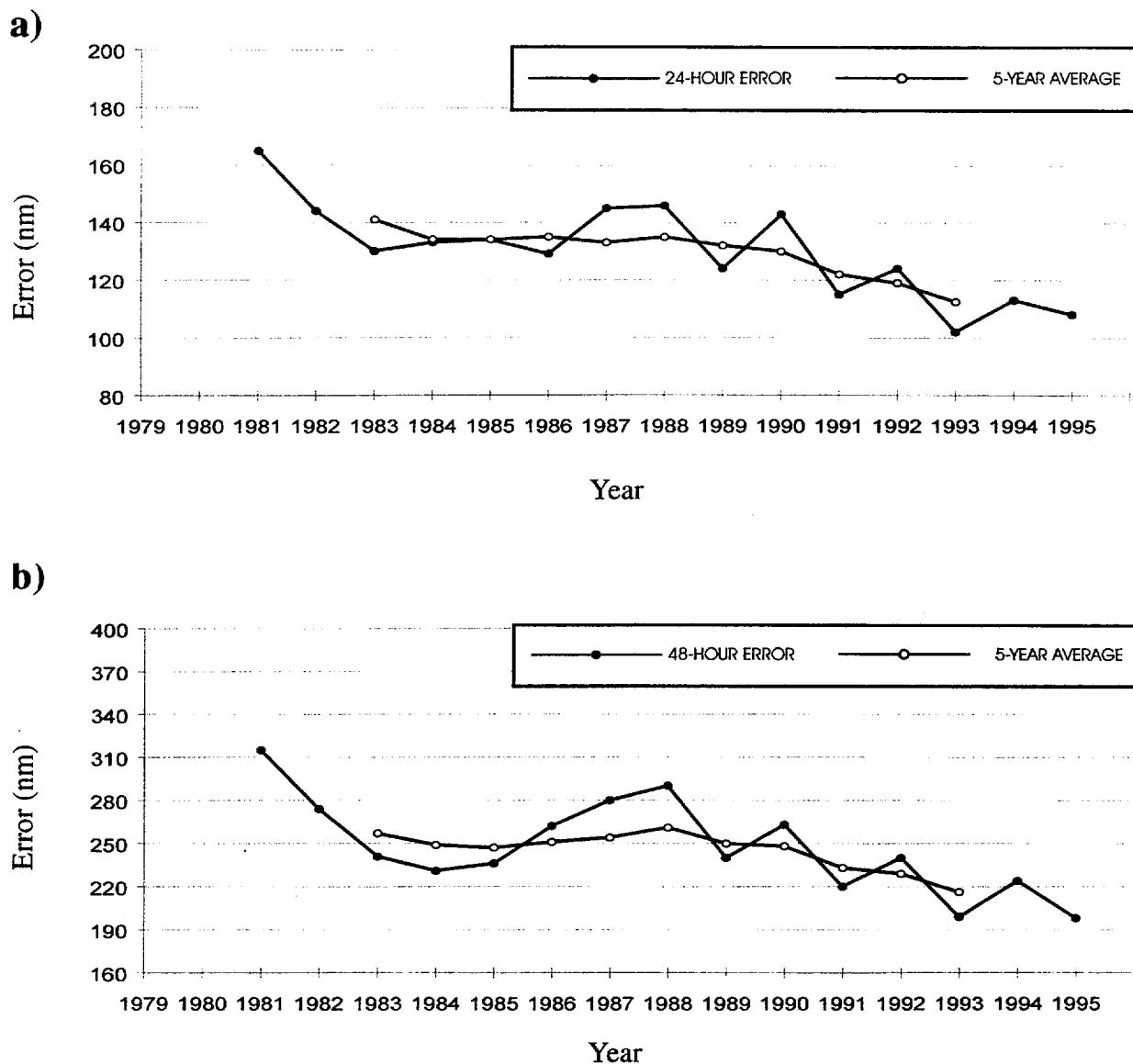


Figure 5-7 Mean track forecast errors (nm) and 5-year running mean for a) 24 hours and b) 48 hours for South Pacific and South Indian Ocean tropical cyclones for the period 1981 to 1995.

5.2 COMPARISON OF OBJECTIVE TECHNIQUES

JTWC uses a variety of objective techniques for guidance in the warning preparation process. Multiple techniques are required, because each technique has particular strengths and weaknesses which vary by basin, numerical model initialization, time of year, synoptic situation and forecast period. The accuracy of objective aid forecasts depends on both the specified position and the past motion of the tropical cyclone as determined by the working best track. JTWC initializes its objective techniques using an extrapolated working best track position so that the output of the techniques will start at the valid time of the next warning initial position.

Unless stated otherwise, all the objective techniques discussed below run in all basins covered by JTWC's AOR and provide forecast positions at 12-, 24-, 36-, 48-, and 72-hours unless the technique aborts prematurely during computations. The techniques can be divided into six general categories: extrapolation, climatology and analogs, statistical, dynamic, hybrids, and empirical or analytical.

5.2.1 EXTRAPOLATION (XTRP) — Past speed and direction are computed using the rhumb line distance between the current and 12-hour old positions of the tropical cyclone. Extrapolation from the current warning position is used to compute forecast positions.

5.2.2 CLIMATOLOGY and ANALOGS

5.2.2.1 CLIMATOLOGY (CLIM) — Employs time and location windows relative to the current position of the tropical cyclone to determine which historical storms will be used to compute the forecast. The historical data base is 1945-1981 for the Northwest Pacific, and 1900 to 1990 for the rest of JTWC's AOR. Objective intensity forecasts are available from

these data bases. Scatter diagrams of expected tropical cyclone motion at bifurcation points are also available from these data bases.

5.2.2.2 ANALOG — A revised Typhoon Analog 1993 (TYAN93) picks the top matches with the basin climatology of tropical cyclone best tracks. Matches are based upon the differences between the direction and speed of the superimposed best track positions and the past direction and speed of the cyclone. Specifically, the directions and speeds are calculated from the 12-hour old position to the "fix" position and the 24-hr old position to the "fix" position. Separate comparisons are made for climatology cyclone tracks classified as "straight", "recurver" and "other". There is also a "total" group, that includes the top matches without regard to classification of tracks.

TYAN93 works the same in all basins. The time-window is +/- 35 days from the "fix." The space-window is +/- 2.5 degrees latitude and +/- 5 degrees longitude from the "fix" position on the first pass of each forecast. The maximum-wind-speed window is as follows (for basins with climatology wind speeds): a. If "fix" wind speed is \leq 25 kt, climatology cyclone wind speed must be \leq 30 kt. b. If "fix" wind speed is 30 kt, climatology cyclone wind speed must be in range from 25 to 35 kt. c. If "fix" wind speed is \geq 35 kt, climatology cyclone wind speed must be at least 35 kt. Matching is based upon weighted direction and speed errors. Forecasting is based upon "straight" and "recurver" type climatology tropical cyclones, where the 12-hour and 24-hour best "straight" ("recurver") matches are combined into one set of best matches for "straight" ("recurver").

5.2.3 STATISTICAL

5.2.3.1 CLIMATOLOGY AND PERSISTENCE (CLIPER or CLIP) — A statistical regression technique that is based on climatology, current position and 12-hour and 24-hour past move-

ment. This technique is used as a crude baseline against which to measure the forecast skill of other, more sophisticated techniques. CLIP in the western North Pacific uses third-order regression equations, and is based on the work of Xu and Neumann (1985). CLIPER has been available outside this basin since mid-1990, with regression coefficients recently recomputed by FNMOC based on the updated 1900-1989 data base.

5.2.3.2 COLORADO STATE UNIVERSITY MODEL (CSUM) — A statistical-dynamical technique based on the work of Matsumoto (1984). Predictor parameters include the current and 24-hr old position of the storm, heights from the current and 24-hr old NOGAPS 500-mb analyses, and heights from the 24-hr and 48-hr NOGAPS 500-mb prognoses. Height values from 200-mb fields are substituted for storms that have an intensity exceeding 90 kt and are located north of the subtropical ridge. Three distinct sets of regression equations are used depending on whether the storm's direction of motion falls into "below," "on," or "above" the subtropical ridge categories. During the development of the regression equation coefficients for CSUM, the so-called "perfect prog" approach was used, in which verifying analyses were substituted for the numerical prognoses that are used when CSUM is run operationally. Thus, CSUM was not "tuned" to any particular version of NOGAPS, and in fact, the performance of CSUM should presumably improve as new versions of NOGAPS improve. CSUM runs only in the western North Pacific, South China Sea, and North Indian Ocean basins.

5.2.3.3 JTWC92 or JT92 - JTWC92 is a statistical-dynamical model for the western North Pacific Ocean basin which forecasts tropical cyclone positions at 12-hour intervals to 72 hours. The model uses the deep-layer mean height field derived from the NOGAPS forecast fields. These deep-layer mean height fields are

spectrally truncated to wave numbers 0 through 18 prior to use in JTWC92. Separate forecasts are made for each position. That is, the forecast 24-hour position is not a 12-hour forecast from the forecasted 12-hour position.

JTWC92 uses five internal sub-models which are blended and iterated to produce the final forecasts. The first sub-model is a statistical blend of climatology and persistence, known as CLIPER. The second sub-model is an analysis mode predictor, which only uses the "analysis" field. The third sub-model is the forecast mode predictor, which uses only the forecast fields. The fourth sub-model is a combination of 1 and 2 to produce a "first guess" of the 12-hourly forecast positions. The fifth sub-model uses the output of the "first guess" combined with 1,2, and 3 to produce the forecasts. The iteration is accomplished by using the output of sub-model 5 as though it were the output from sub-model 4. The optimum number of iterations has been determined to be three.

When JTWC92 is used in the operational mode, all the NOGAPS fields are forecast fields. The 00Z and 12Z tropical forecasts are based upon the previous 12-hour old synoptic time NOGAPS forecasts. The 06Z and 18Z tropical forecasts are based on the previous 00Z and 12Z NOGAPS forecasts, respectively. Therefore, operationally, the second sub-model uses forecast fields and not analysis fields.

5.2.4 DYNAMIC

5.2.4.1 NOGAPS VORTEX TRACKING ROUTINE(NGPS/X)—Tropical cyclone vortices are tracked at FNMOC by converting the 1000-mb u and v wind component fields into isogons. The intersection of isogons are either the center of a cyclonic or anticyclonic circulation, or a col. The tracking program starts at the last known location of the cyclone - a warning position. Based on this position and the last known speed and direction of movement, the

program hunts for the next cyclonic center representing the tropical cyclone. Confidence factors are generated within the program and are modified, as required, by a quality control program that formats the data for transmission.

5.2.4.2 ONE-WAY (INTERACTIVE) TROPICAL CYCLONE MODEL (OTCM) — This technique is a coarse resolution (205-km grid), three layer, primitive equation model with a horizontal domain of 6400 x 4700 km. OTCM is initialized using 6-hour or 12-hour prognostic fields from the latest NOGAPS run, and the initial fields are smoothed and adjusted in the vicinity of the storm to induce a persistence bias into OTCM's forecast. A symmetric bogus vortex is then inserted, and the boundaries updated every 12 hours by NOGAPS fields as the integration proceeds. The bogus vortex is maintained against frictional dissipation by an analytical heating function. The forecast positions are based on the movement of the vortex in the lowest layer of the model (effectively 850-mb).

5.2.4.3 FNOC BETA AND ADVECTION MODEL (FBAM) — This model is an adaptation of the Beta and Advection model used by NCEP. The forecast motion results from a calculation of environmental steering and an empirical correction for the observed vector difference between that steering and the 12-hour old storm motion. The steering is computed from the NOGAPS Deep Layer Mean (DLM) wind fields which are a weighted average of the wind fields computed for the 1000-mb to 100-mb levels. The difference between past storm motion and the DLM steering is treated as if the storm were a Rossby wave with an "effective radius" propagating in response to the horizontal gradient of the coriolis parameter, beta. The forecast proceeds in one-hour steps, recomputing the effective radius as beta changes with storm latitude, and blending in a persistence bias for the first 12 hours.

5.2.5 HYBRIDS

5.2.5.1 HALF PERSISTENCE AND CLIMATOLOGY (HPAC) — Forecast positions generated by equally weighting the forecasts given by XTRP and CLIM.

5.2.5.2 BLENDED (BLND) — A simple average of JTWC's six primary forecast aids: OTCM, CSUM, FBAM, JT92, CLIP, and HPAC.

5.2.5.3 WEIGHTED (WGTD) — A weighted average of the forecast guidance used to compute BLND: OTCM (29%), CSUM (22%), FBAM (14%), JT92 (14%), HPAC (14%), and CLIP (7%).

5.2.5.4 DYNAMIC AVERAGE (DAVE) — A simple average of all dynamic forecast aids: NOGAPS (NGPS), Bracknell (EGRR), Japanese Typhoon Model (JTYP), JT92, FBAM, OTCM and CSUM.

5.2.6 EMPIRICAL OR ANALYTICAL

5.2.6.1 DVORAK — An estimation of a tropical cyclone's current and 24-hour forecast intensity is made from the interpretation of satellite imagery (Dvorak, 1984). These intensity estimates are used with other intensity related data and trends to forecast short-term tropical cyclone intensity.

5.2.6.2 MARTIN/HOLLAND — The technique adapts an earlier work (Holland, 1980) and specifically addresses the need for realistic 35-, 50- and 100-kt (18-, 26- and 51-m/sec) wind radii around tropical cyclones. It solves equations for basic gradient wind relations within the tropical cyclone area, using input parameters obtained from enhanced infrared satellite imagery. The diagnosis also includes an asymmetric area of winds caused by tropical cyclone

movement. Satellite-derived size and intensity parameters are also used to diagnose internal steering components of tropical cyclone motion known collectively as "beta-drift".

5.2.6.3 TYPHOON ACCELERATION PREDICTION TECHNIQUE (TAPT) — This technique (Weir, 1982) utilizes upper-tropospheric and surface wind fields to estimate acceleration associated with the tropical cyclone's interaction with the mid-latitude westerlies. It includes guidelines for the duration of acceleration, upper limits and probable path of the cyclone.

5.3 TESTING AND RESULTS

A comparison of selected techniques is included in Table 5-5 for all western North Pacific tropical cyclones, Table 5-6 for all North Indian Ocean tropical cyclones and Table 5-7 for the Southern Hemisphere. For example, in Table 5-5 for the 12-hour mean forecast error, 687 cases available for a (homogeneous) comparison, the average forecast error at 12 hours was 92 nm (170 km) for CLIP and 89 nm (165 km) for FBAM. The difference of 3 nm (6 km) is shown in the lower right. (Differences are not always exact, due to computational round-off which occurs for each of the cases available for comparison).

TABLE 5-5 1995 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES IN THE NORTHWEST PACIFIC
(1 JAN 1995 - 31 DEC 1995)

12-HOUR MEAN FORECAST ERROR (NM)

	JTWC		DAVE		NGPS		OTCM		CSUM		FBAM		CLIP		JT92	
JTWC	584	72														
	72	0														
DAVE	511	71	601	92												
	77	6	92	0												
NGPS	430	64	393	70	447	131										
	126	62	130	60	131	0										
OTCM	553	70	584	92	429	125	683	92								
	84	14	87	-5	80	-45	92	0								
CSUM	564	71	596	92	432	126	681	92	694	98						
	82	11	92	0	76	-50	98	6	98	0						
FBAM	557	71	589	92	430	125	674	92	686	98	687	89				
	81	10	85	-7	75	-50	88	-4	89	-9	89	0				
CLIP	567	71	597	92	434	125	683	92	694	98	687	89	697	92		
	84	13	89	-3	78	-47	91	-1	92	-6	92	3	92	0		
JT92	564	71	596	92	432	126	680	92	693	97	685	89	693	92	693	164
	84	13	130	38	72	-54	165	73	164	67	165	76	164	72	164	0

24-HOUR MEAN FORECAST ERROR (NM)

	JTWC		DAVE		NGPS		OTCM		CSUM		FBAM		CLIP		JT92	
JTWC	539	123														
	123	0														
DAVE	474	123	569	137												
	117	-6	137	0												
NGPS	393	113	363	111	414	146										
	140	27	141	30	146	0										
OTCM	505	119	542	132	391	137	637	147								
	139	20	142	10	134	-3	147	0								
CSUM	527	122	566	137	402	141	635	147	662	168						
	141	19	162	25	133	-8	159	12	168	0						
FBAM	522	123	561	137	400	140	630	147	656	169	657	135				
	125	2	131	-6	121	-19	131	-16	135	-34	135	0				
CLIP	530	122	567	137	403	141	637	147	662	168	657	135	665	151		
	144	22	149	12	135	-6	147	0	151	-17	151	16	151	0		
JT92	527	122	566	137	402	141	634	147	661	168	655	135	661	151	661	187
	126	4	168	31	118	-23	171	24	187	19	188	53	187	36	187	0

**Table 5-5 (CONTINUED) 1995 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES
IN THE NORTHWESTERN PACIFIC
(1 JAN 1995 - 31 DEC 1995)**

36-HOUR MEAN FORECAST ERROR (NM)

	JTWC	DAVE	NGPS	OTCM	CSUM	FBAM	CLIP	JT92
JTWC	489 170							
	170 0							
DAVE	435 171	529 168						
	160 -11	168 0						
NGPS	333 157	309 151	354 195					
	188 31	187 36	195 0					
OTCM	455 163	499 164	333 185	586 200				
	195 32	199 35	190 5	200 0				
CSUM	481 170	524 166	345 189	582 200	612 209			
	198 28	209 43	187 -2	200 0	209 0			
FBAM	476 171	520 168	342 189	579 201	606 209	610 185		
	176 5	181 13	171 -18	180 -21	184 -25	185 0		
CLIP	483 170	526 168	345 189	586 200	612 209	610 185	617 212	
	206 36	210 42	188 -1	202 2	210 1	212 27	212 0	
JT92	481 170	525 168	345 189	583 201	611 209	608 185	614 212	614 232
	176 6	202 34	161 -28	218 17	214 5	232 47	232 20	232 0

48-HOUR MEAN FORECAST ERROR (NM)

	JTWC	DAVE	NGPS	OTCM	CSUM	FBAM	CLIP	JT92
JTWC	421 215							
	215 0							
DAVE	374 215	488 216						
	208 -7	216 0						
NGPS	283 201	267 202	305 259					
	254 53	256 54	259 0					
OTCM	390 207	459 213	288 254	540 260				
	256 49	260 47	259 5	260 0				
CSUM	414 215	484 216	296 254	538 260	568 259			
	263 48	264 48	245 -9	250 -10	259 0			
FBAM	410 216	479 216	293 253	533 261	562 259	563 245		
	235 19	241 25	241 -12	237 -24	245 -14	245 0		
CLIP	416 215	485 216	296 254	540 260	568 259	563 245	570 273	
	275 60	273 57	245 -9	260 0	273 14	273 28	273 0	
JT92	414 215	484 216	296 254	537 260	567 259	561 245	567 273	567 284
	238 23	264 48	225 -29	261 1	284 25	283 38	284 11	284 0

72-HOUR MEAN FORECAST ERROR (NM)

	JTWC	DAVE	NGPS	OTCM	CSUM	FBAM	CLIP	JT92
JTWC	319 325							
	325 0							
DAVE	280 326	393 331						
	333 7	331 0						
NGPS	207 315	199 339	234 383					
	382 67	384 45	383 0					
OTCM	284 316	354 323	207 376	422 386				
	387 71	392 69	412 36	386 0				
CSUM	314 324	390 330	227 379	422 386	466 366			
	380 56	378 48	386 7	347 -39	366 0			
FBAM	313 324	387 329	225 378	418 387	462 366	463 375		
	368 44	372 43	408 30	359 -28	376 10	375 0		
CLIP	316 324	391 329	227 379	422 386	464 367	461 373	466 384	
	407 83	391 62	376 -3	367 -19	384 17	385 12	384 0	
JT92	313 324	389 330	226 378	420 387	463 367	460 376	462 384	463 383
	358 34	379 49	343 -35	363 -24	383 16	383 7	381 -3	383 0

TABLE 5-6

1995 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES
IN THE NORTH INDIAN OCEAN (1 JAN 1995 - 31 DEC 1995)

12-HOUR MEAN FORECAST ERROR (NM)

JTWC	JTWC	NGPS	OTCM	CSUM	FBAM	CLIP	HPAC	WGTD
	52	78						
	78	0						
NGPS	40	78	40	114				
	114	36	114	0				
OTCM	45	77	39	111	46	118		
	118	41	122	11	118	0		
CSUM	46	78	40	114	46	118	47	123
	124	46	124	10	122	4	123	0
FBAM	46	78	40	114	46	118	47	123
	90	12	89	-25	87	-31	88	-35
CLIP	46	78	40	114	46	118	47	123
	93	15	94	-20	91	-27	92	-31
HPAC	46	78	40	114	46	118	47	123
	97	19	99	-15	95	-23	95	-28
WGTD	32	78	27	124	32	125	33	122
	103	25	107	-17	101	-24	101	-21
					101	-21	101	13
					101	10	101	10
					101	6	101	0

24-HOUR MEAN FORECAST ERROR (NM)

JTWC	JTWC	NGPS	OTCM	CSUM	FBAM	CLIP	HPAC	WGTD
	47	138						
	138	0						
NGPS	38	143	38	169				
	169	26	169	0				
OTCM	38	129	32	165	39	229		
	229	100	242	77	229	0		
CSUM	44	139	38	169	39	229	45	288
	288	149	289	120	290	61	288	0
FBAM	44	139	38	169	39	229	45	288
	149	10	150	-19	135	-94	147	-141
CLIP	44	139	38	169	39	229	45	288
	163	24	168	-1	146	-83	161	-127
HPAC	44	139	38	169	39	229	45	288
	170	31	178	9	151	-78	167	-121
WGTD	30	135	25	176	26	231	31	279
	188	53	201	25	161	-70	184	-95
					184	-95	184	35
					184	35	184	23
					184	23	184	21
					184	21	184	0

36-HOUR MEAN FORECAST ERROR (NM)

JTWC	JTWC	NGPS	OTCM	CSUM	FBAM	CLIP	HPAC	WGTD
	38	197						
	197	0						
NGPS	33	207	33	208				
	208	1	208	0				
OTCM	29	171	25	177	30	321		
	320	149	335	158	321	0		
CSUM	37	199	33	208	30	321	38	459
	458	259	454	246	469	148	459	0
FBAM	37	199	33	208	30	321	38	459
	215	16	219	11	189	-132	213	-246
CLIP	37	199	33	208	30	321	38	459
	238	39	250	42	191	-130	235	-224
HPAC	37	199	33	208	30	321	38	459
	243	44	255	47	191	-130	239	-220
WGTD	27	200	23	217	21	325	28	453
	269	69	291	74	210	-115	263	-190
					263	-190	263	50
					263	50	263	22
					263	22	263	16
					263	16	263	0

TABLE 5-6 (CONTINUED) 1995 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES
IN THE NORTH INDIAN OCEAN (1 JAN 1995 - 31 DEC 1995)

48-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		OTCM	CSUM		FBAM	CLIP	HPAC	WGTD
JTWC	32 262									
	262 0									
NGPS	25 282	25	285							
	285 3	285	0							
OTCM	25 218	19	245	26 389						
	388 170	415	170	389 0						
CSUM	31 265	25	285	26 389	32	620				
	617 352	584	299	634 245	620	0				
FBAM	31 265	25	285	26 389	32	620	32 256			
	257 -8	255	-30	230 -159	256	-364	256 0			
CLIP	31 265	25	285	26 389	32	620	32 256	32 301		
	304 39	318	33	238 -151	301	-319	301 45	301 0		
HPAC	31 265	25	285	26 389	32	620	32 256	32 301	32 298	
	303 38	316	31	233 -156	298	-322	298 42	298 -3	298 0	
WGTD	23 267	18	285	19 397	24	626	24 255	24 319	24 313	24 315
	325 58	352	67	249 -148	315	-311	315 60	315 -4	315 2	315 0

72-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS		OTCM	CSUM		FBAM	CLIP	HPAC	WGTD
JTWC	20 342									
	342 0									
NGPS	14 358	14	326							
	326 -32	326	0							
OTCM	17 324	12	260	18 504						
	484 160	473	213	504 0						
CSUM	19 351	14	326	18 504	20	866				
	856 505	810	484	875 371	866	0				
FBAM	19 351	14	326	18 504	20	866	20 297			
	302 -49	298	-28	288 -216	297	-569	297 0			
CLIP	19 351	14	326	18 504	20	866	20 297	20 397		
	388 37	399	73	370 -134	397	-469	397 100	397 0		
HPAC	19 351	14	326	18 504	20	866	20 297	20 397	20 388	
	383 32	387	61	357 -147	388	-478	388 91	388 -9	388 0	
WGTD	16 388	11	374	15 566	17	905	17 302	17 444	17 438	17 384
	386 -2	405	31	359 -207	384	-521	384 82	384 -60	384 -54	384 0

TABLE 5-7 1995 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES
IN THE SOUTHERN HEMISPHERE (1 JUL 1994 - 30 JUN 1995)

12-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS	OTCM	FBAM	CLIP	HPAC	WGTD	CLIM
JTWC	244	63						
	63	0						
NGPS	172	63	262	83				
	85	22	83	0				
OTCM	226	62	205	86	321	79		
	77	15	78	-8	79	0		
FBAM	224	64	205	87	316	79	319	67
	64	0	67	-20	65	-14	67	0
CLIP	229	64	208	86	321	79	319	67
	83	19	84	-2	83	4	86	0
HPAC	229	64	208	86	321	79	319	67
	75	11	77	-9	75	-4	77	10
WGTD	189	62	176	87	263	79	261	66
	73	11	75	-12	72	-7	75	9
CLIM	228	64	208	86	319	79	317	67
	86	22	87	1	84	5	86	19

24-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS	OTCM	FBAM	CLIP	HPAC	WGTD	CLIM
JTWC	222	108						
	108	0						
NGPS	160	112	246	125				
	125	13	125	0				
OTCM	202	103	189	121	292	131		
	130	27	129	8	131	0		
FBAM	206	109	191	126	288	132	298	107
	106	-3	115	-11	104	-28	107	0
CLIP	210	109	194	125	292	131	298	107
	149	40	151	26	146	15	152	45
HPAC	210	109	194	125	292	131	298	107
	132	23	134	9	125	-6	130	23
WGTD	172	103	163	125	240	130	244	105
	123	20	125	0	115	-15	122	17
CLIM	209	109	194	125	290	131	296	107
	162	53	164	39	152	21	159	52

36-HOUR MEAN FORECAST ERROR (NM)

	JTWC	NGPS	OTCM	FBAM	CLIP	HPAC	WGTD	CLIM
JTWC	198	151						
	151	0						
NGPS	133	153	209	179				
	166	13	179	0				
OTCM	175	147	156	168	261	186		
	181	34	181	13	186	0		
FBAM	184	151	165	178	258	187	278	159
	153	2	170	-8	154	-33	159	0
CLIP	187	151	168	176	261	186	278	159
	200	49	204	28	200	14	211	52
HPAC	187	151	168	176	261	186	278	159
	178	27	184	8	177	-9	183	24
WGTD	154	144	142	175	214	183	229	152
	163	19	172	-3	161	-22	169	17
CLIM	186	151	168	176	259	186	276	159
	221	70	224	48	217	31	221	62

**TABLE 5-7 (CONTINUED) 1995 ERROR STATISTICS FOR SELECTED OBJECTIVE TECHNIQUES
IN THE SOUTHERN HEMISPHERE (1 JUL 1994 - 30 JUN 1995)**

48-HOUR MEAN FORECAST ERROR (NM)												
	JTWC	NGPS		OTCM		FBAM		CLIP		HPAC	WGTD	CLIM
JTWC	175	198										
	198	0										
NGPS	109	191	174	229								
	203	12	229	0								
OTCM	156	198	131	201	238	254						
	257	59	238	37	254	0						
FBAM	161	197	136	223	235	255	253	209				
	195	-2	220	-3	201	-54	209	0				
CLIP	164	197	139	222	238	254	253	209	256	270		
	256	59	250	28	259	5	271	62	270	0		
HPAC	164	197	139	222	238	254	253	209	256	270	256	238
	233	36	240	18	232	-22	239	30	238	-32	238	0
WGTD	136	194	117	218	194	249	207	197	210	260	210	230
	219	25	224	6	212	-37	219	22	218	-42	218	-12
CLIM	163	196	139	222	236	253	251	209	254	269	254	238
	276	80	288	66	274	21	281	72	280	11	280	42
72-HOUR MEAN FORECAST ERROR (NM)												
	CLIP	JTWC		NGPS		OTCM		FBAM		HPAC	CLIM	
CLIP	203	405										
	405	0										
JTWC	50	427	53	291								
	287	-140	291	0								
NGPS	102	360	38	287	124	341						
	340	-20	387	100	341	0						
OTCM	187	398	47	281	98	261	187	405				
	405	7	381	100	387	126	405	0				
FBAM	200	406	49	286	99	336	184	406	200	313		
	313	-93	258	-28	310	-26	308	-98	313	0		
HPAC	203	405	50	287	102	340	187	405	200	313	203	347
	347	-58	349	62	331	-9	344	-61	348	35	347	0
CLIM	201	404	50	287	102	340	185	405	198	313	201	348
	384	-20	405	118	383	43	380	-25	386	73	384	36
201 384												